Technical Report No. 32-717

The Design of the Ranger Television System to Obtain High-Resolution Photographs of the Lunar Surface

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PREFACE

The television system for the *Ranger* spacecraft was designed and manufactured by the Astro-Electronics Division of Radio Corporation of America, under contract to the Jet Propulsion Laboratory. Coauthors of this Report are Donald H. Kindt of the Jet Propulsion Laboratory and Joseph R. Staniszewski of RCA Astro-Electronics Division.

ABSTRACT

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The design of the television system incorporated into the *Ranger* spacecraft, which obtained the first high-resolution close-up photographs of the lunar surface on July 31, 1964, is described. The entire system design is presented, including both the ground recovery system and the flight system. The 380-lb flight system includes six cameras, sequencers, command-control circuitry, two transmitters, telemetry system, batteries, power supplies, and thermal control surfaces. Particular emphasis is given to the design of the cameras, the sequencing and logic required for the various commands (including the interfaces with the "bus" portion of the spacecraft), and the transmitter configuration. Such characteristics as camera parameters (sensitivity, line density, spectral response, resolution), the programming of the camera readouts to utilize the available transmitter bandwidth, and the transmission of the outputs of the two transmitters simultaneously over one high-gain antenna are presented in detail. A brief description is given of the mission flight sequence, along with some of the constraints and unknown factors that influenced the design of the television system. The design of the ground recovery system is presented, showing the interfaces with the Deep Space Instrumentation Facility, as well as those with the flight television system. A brief analysis of the *Ranger VII* flight performance is given, along with a comparison with system design goals.

Author

I. *RANGER* SPACECRAFT

The *Ranger* television system was designed to be integrated into the *Ranger* spacecraft in support of the mission objectives for the *Ranger* program. These objectives are to obtain television pictures of the lunar surface that will be of benefit to both the scientific program and the United States manned lunar program. These pictures should be at least an order of magnitude better in resolution than any available Earth-based photography.

The *Ranger* spacecraft, Fig. 1, consists of two major elements—the television system and the spacecraft bus, which provides a space-stabilized vehicle for the TV system. The total spacecraft (bus and TV) weighs about 810 lb; the weight of the TV system is about 380 lb. The bus consists of several systems, which are the radio, data encoder, and command systems; the central computer and sequencer (CC&S) system; the attitude-control system; the power system; and the midcourse propulsion system. The power system, which derives its power from two solar panels when the spacecraft is oriented toward the Sun and from batteries during other periods, supplies all the power required by the bus portion of the spacecraft. The attitude-control system provides for attitude stabilization during the major portion of the flight, so that the solar panels will be oriented toward the Sun at the same time that the high-gain antenna of the radio system

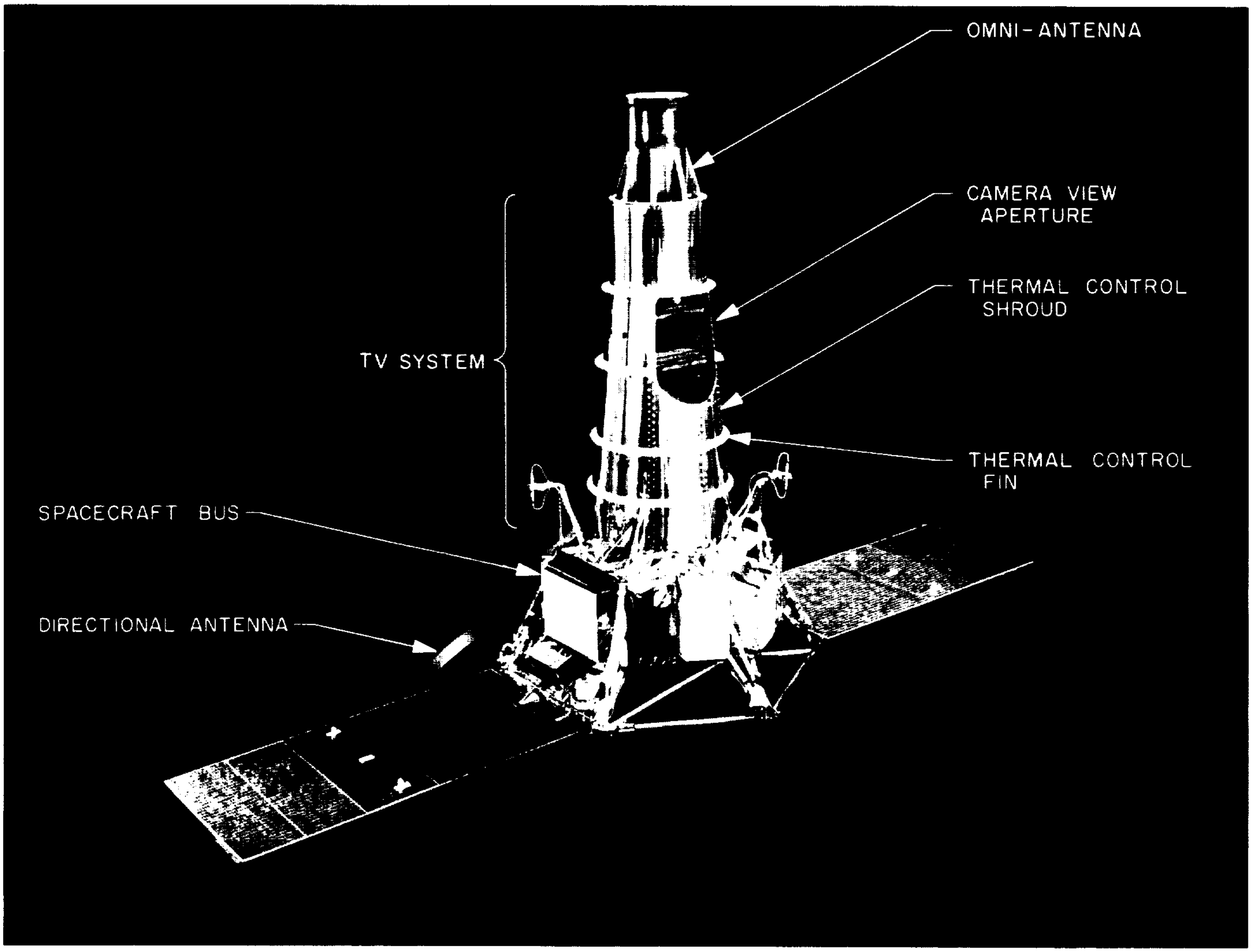

Fig. 1. *Ranger* configuration

is pointed toward the Earth. It also provides the capability for maneuvers to initially acquire the Sun and the Earth, to correct any trajectory errors during flight in conjunction with the midcourse propulsion system, and to align the cameras of the TV system in relation to the lunar surface prior to impacting the Moon. The radio system provides a two-way link between the Earth and the spacecraft for transmission of telemetry from the data encoder system to Earth, and to send command information from Earth to the spacecraft command system. The CC&S provides all of the on-board timing for the various spacecraft functions.

The *Ranger* spacecraft is boosted to an Earth-to-Moon trajectory by means of an *Atlas-Agena B* launch vehicle. After injection on this trajectory has taken place, the spacecraft is separated from the *Agena* and begins its acquisition process. The first step is the unfolding of the solar panels, followed by the moving of the high-gain directional antenna to a preset angle. The spacecraft then commences Sun acquisition, in which the roll axis is pointed toward the Sun. The solar panels are at that time oriented in such a manner as to convert solar energy to electrical power for use by the spacecraft bus during the cruise mode of flight. A roll maneuver is then performed to point the high-gain antenna toward the Earth by means of an optical Earth sensor. During most of the flight, the spacecraft remains attitude-stabilized and transmits information from the bus and the TV system to Earth.

At approximately 16 hr after injection, the cruise mode is interrupted, and a trajectory correction maneuver is performed. The midcourse correction maneuver is initiated by a real-time command sent from Earth. The maneuver consists of orienting the spacecraft so that a corrective velocity increment may be imparted by the midcourse propulsion system. The magnitude and direction of the velocity increment necessary to effect a successful lunar encounter is computed from tracking data received from the spacecraft. After completion of the midcourse maneuver, the spacecraft proceeds to automatically reacquire the Sun and Earth as previously described.

About 60 min before lunar impact, the terminal maneuver is initiated. The maneuver consists of orienting the spacecraft so that the directional antenna remains pointed toward the Earth, and the television cameras are pointed along the velocity vector to give the best pictures of the lunar surface. The television system is then activated and transmits video information to Earth. The entire spacecraft then impacts the lunar surface, thus ending the mission.

II. TELEVISION FLIGHT SYSTEM

The TV system contains many elements, such as the six cameras, sequencers, two transmitters, telemetry system, two batteries, and power supplies (Fig. 2). The TV system is electrically complete and independent of the spacecraft bus, with the exception of commands received either from the bus command system or the CC&S, and the utilization of the bus high-gain directional antenna. In addition, the TV system turn-on circuitry is locked out by the bus during the boost phase of flight to prevent any premature turn-on of the TV system. The philosophy behind the design of the TV system is to make it as self-sufficient as possible and also to provide for as much

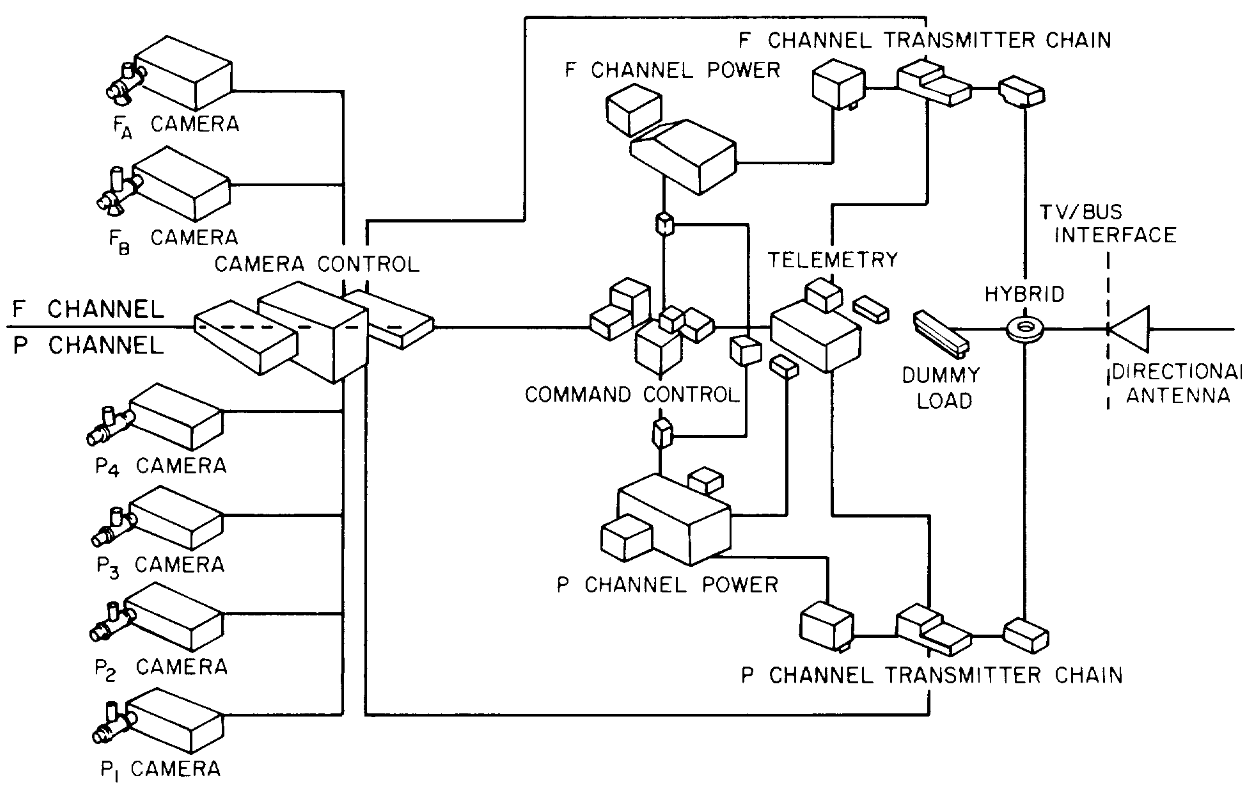

Fig. 2. Block diagram of the *Ranger* TV system

redundancy as possible to ensure meeting the mission objectives.

The heart of the TV system is the cameras. The six cameras are of two basic types: fully scanned (F) and partially scanned (P). There are two F-type cameras (A and B) and four P-type cameras (1, 2, 3, and 4). Both types of cameras contain a 1-in. vidicon. The F-type cameras have 1132 scanning lines in a 0.44-in.-square format, and the P-type cameras have 290 scanning lines in a 0.11-in.-square format. This provides for different fields of view as well as for different readout times. In addition, one F camera and two P cameras have 25-mm F/0.95 lenses; and the other F camera and two P cameras have 76-mm F/2 lenses. The resultant fields of view are shown in Fig. 3. This arrangement was chosen to provide various fields of view and various resolution capabilities to help in locating and indexing the resultant photographs. Also, the camera gains are set up to cover a wide dynamic range (Fig. 4), since the exact nature of the lunar lighting conditions was not known prior to the *Ranger VII* flight. The F cameras are read out alternately during a 2.56-sec period each, and their video output is transmitted over one of the two communications channels. The P cameras are read out sequentially during a 0.2-sec period each, and their video output is transmitted over the other communications channel. Each camera consists of a camera head assembly and its individual camera electronics assembly. Synchronization and control signals for the F and P cameras are provided by the F and P camera sequencers respectively. Each sequencer contains a video combiner, control programmer, camera sequencer, and power supply. This group generates synchronizing signals for the individual cameras and applies the composite video signal to the respective RF transmitter channel modulator. Timing for an 80-sec transmitter warm-up period is also provided.

Each transmitter channel consists of an L-band FM modulator and multiplier stages, intermediate power amplifier, 60-w power amplifier, telemetry processor, and transmitter power supply. A 4-port hybrid ring is used to combine the outputs of the two channels, so that both channels can be transmitted over the one high-gain directional antenna. A dummy load is provided to dissipate the combining losses. Each transmitter operates within a

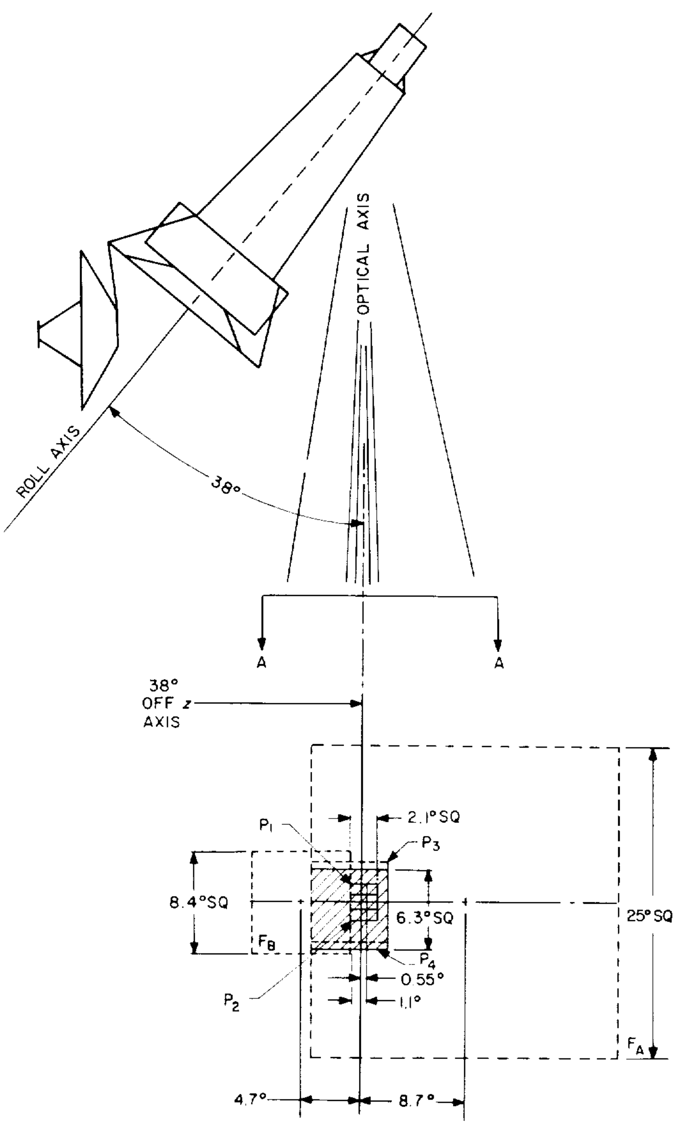

Fig. 3. Camera fields of view and optical axis orientation

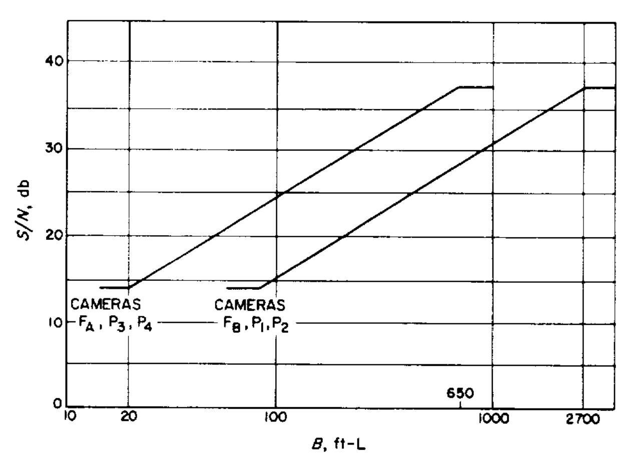

Fig. 4. Dynamic range of cameras

bandwidth of 900 kc, with the output of the F- and P-channel transmitters centered at 959.52 and 960.58 Mc, respectively. A 160-kc band between TV transmitter channels is reserved for the spacecraft bus transmitter.

A cruise-mode telemetry system is activated prior to launch and operates during the entire flight. A 15-point sampling switch operating at a rate of one point per second is used to sample the critical temperatures and voltages. This telemetry information is sent to the bus data encoder and is transmitted over the bus transmitter on one of the telemetry subcarriers. During the terminal-mode phase of the flight, when the TV system is activated, a terminal-mode telemetry system is also used. This consists of a 90-point sampling switch operating at a rate of three points per second, sampling TV system parameters to provide detailed diagnostic measurements. This telemetry is transmitted over the P-channel transmitter on a 225-kc subcarrier, and over the bus transmitter, replacing the 15-point cruise-mode telemetry. The 15-point cruise-mode telemetry is transmitted on a 225-kc subcarrier on the F-channel transmitter during the terminal mode.

Power is provided for the TV system from two batteries, each having a capacity of about 40 amp-hr. One battery powers all of the F-channel equipment, while the other powers all of the P-channel equipment, thus providing two essentially independent systems. Various power converters are utilized to power the individual elements of each channel.

The structure for the TV system is in the shape of the frustum of a right circular cone topped by a cylindrical section. The primary strength of the structure is provided by a box-spar consisting of stiffened panel sections (Fig. 5). The electronic assemblies mount on structural decks supported by eight longerons. The camera heads mount onto a solid machined camera bracket within the top cylindrical section, with a viewing port cut out of the external thermal shroud.

The thermal control for the TV system is entirely passive, with a thermal shroud (mounted external to the structure) and fins used to control the radiative exchange of energy between the TV system and the outside environment. The thermal mass of the structure is the primary heat sink.

As previously mentioned, there exists a command interface between the TV system and the spacecraft bus in order to activate the TV system at the proper time. There are two methods of turning on the TV system

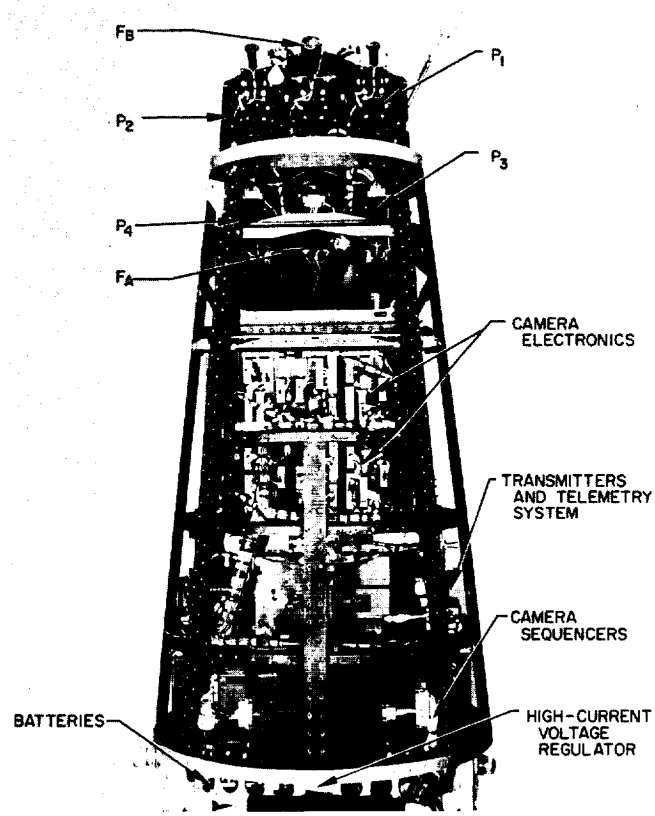

Fig. 5. ***Ranger*** **TV system**

from the bus. One is by command from the CC&S, and the other is by a real-time command from the command system. The CC&S command is a stored command and is counted down by the CC&S during the terminal mode of the flight; this mode is activated by a real-time command from Earth. The turn-on command from the command system is initiated as a real-time command from Earth to back up the CC&S stored command. Either of these start commands activates the entire TV system with the exception of the final power-amplifier stage in each transmitter. An 80-sec warm-up period is provided for this stage, the 80 sec being counted down by the sequencer. As a backup to the sequencer, another stored CC&S command is used to switch from warm-up to full power should the sequencer command fail to do this. The capability also exists to turn the TV system off by means of another real-time command should this be necessary due to an abnormal turn-on.

In addition to the above methods of system turn-on, another method exists within the TV system itself. A backup clock is provided which is activated at spacecraft separation from the *Agena* and then counts down the total flight time of approximately 68 hr (this time is dependent upon the month of launch and is set prior to launch for any particular month). The clock is intended to activate the F channel of the TV system, should the bus commands fail. The midcourse trajectory correction is executed so that this clock time will occur approximately the same time as the normal turn-on commands. The clock status is telemetered over the 15-point cruise-mode telemetry system to check its accuracy. If the clock appears to be running normally, it will be left "on" to activate the F channel; but if it is not running normally, it can be turned off by means of a real-time command sent from Earth through the bus command system. By means of these various commands, there is a high probability that at least one channel will be activated.

III. TELEVISION GROUND RECOVERY SYSTEM

The TV ground recovery system for the reception and recording of the signals from the *Ranger* spacecraft is located at the Deep Space Instrumentation Facility (DSIF) tracking station at Goldstone, California. Three tracking stations are located around the world to provide continuous coverage of the spacecraft, although the equipment necessary to recover the video information from the TV system is located only at Goldstone. The *Ranger* flights are timed so that the lunar encounter occurs while Goldstone is tracking the spacecraft. The purpose of the TV ground recovery system is to receive the RF signal from the spacecraft and convert this into photographic images on 35-mm film. The main elements of the system are receivers, tape recorders, telemetry recorders, and film recorders (Fig. 6). Each receiver is a two-channel device capable of receiving both the F and P channels. There are two receivers for redundancy, although only one is used unless a failure occurs in it, in which case the other is used. The receivers demodulate and separate the video and telemetry information. The telemetry information is recorded on a telemetry chart recorder, and is also sent to a computer at the Jet Propulsion Laboratory (JPL) for automatic reduction. The video information is sent to the film recorders (one for the F channel and one for the P channel). In the F-channel recorder, the video signals from the F_A and F_B cameras are alternately displayed on the cathode-ray tube of the film recorder. The image is recorded on the 35-mm film by an automatic sequencing film camera, so that after development there exists a strip of film with alternate images from the F_A and F_B cameras. The P video is similarly displayed in the P film recorder except

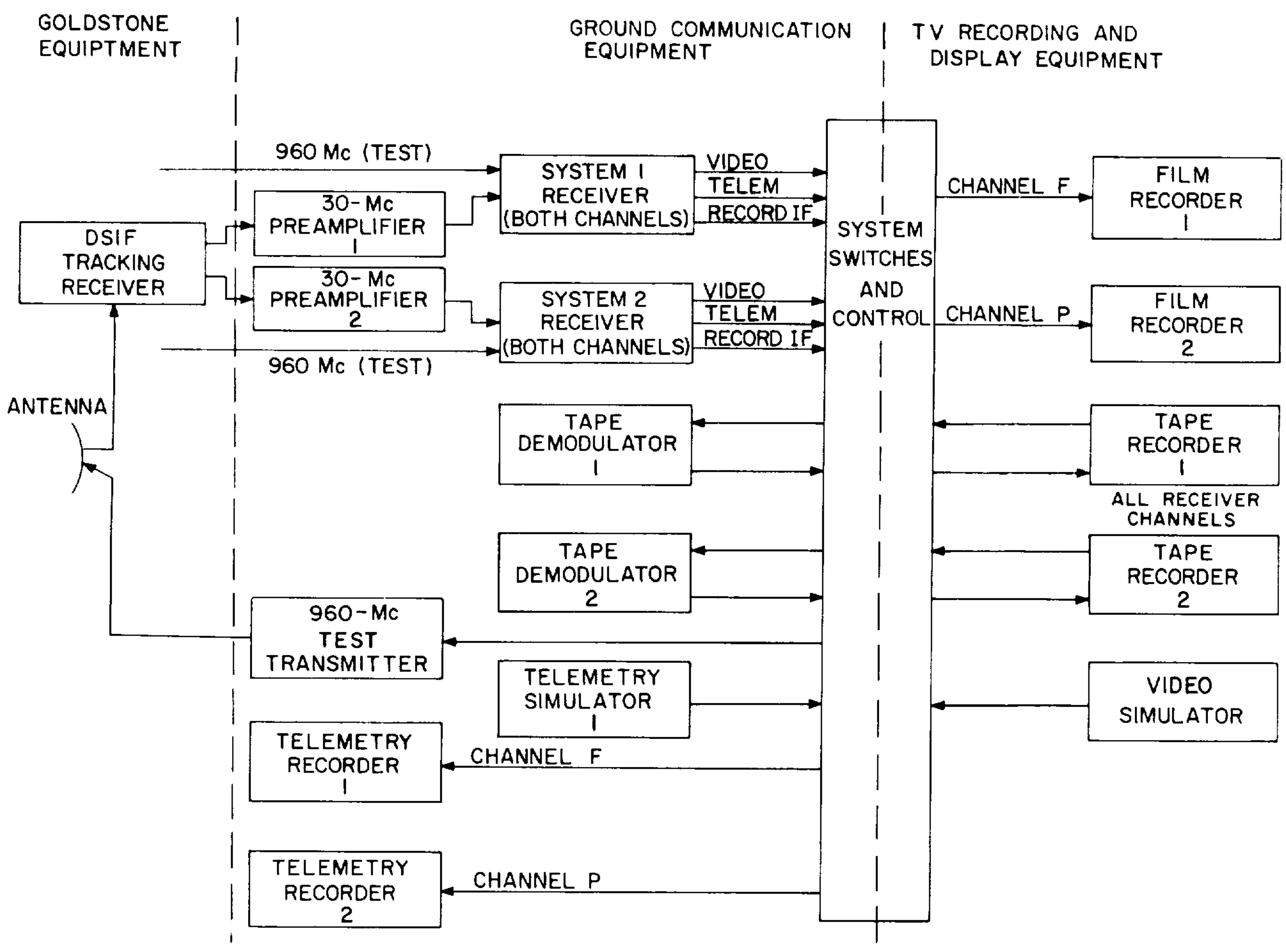

Fig. 6. Functional block diagram of ground receiving and recording system

that the images from the four P cameras are recorded in groups of four per frame of 35-mm film, since they use only about one-fourth as many scan lines as the F cameras. Both film recorders also contain a Polaroid camera which is used to obtain a quick check on the system performance.

In addition to this on-line recording of telemetry and video, the composite signal output of each receiver is recorded on two tape recorders simultaneously. This provides a magnetic tape record that can be played back at any future date through the same recovery equipment to make duplicate film recordings.

IV. TELEVISION FLIGHT SYSTEM DESIGN

The basic design of the TV system is reflected in the camera and communications areas. In considering a television system for the lunar impacting mission, factors such as lunar luminance and approach velocity and the resulting image smear had a profound effect on the camera design. The RF channel allocations and the assignment of Goldstone's maser-equipped 85-ft-diameter antenna to the *Ranger* mission also had their effect on the camera design and on the design of the telecommunications system. The RF allocations provided two separate channels, each with a bandwidth of 900 kc. A review of L-band transmission and modulation systems suggested that a standard FM system would provide overall simplicity in video transmission and retrieval for eventual display and recording. Two conflicting system criteria—that rapid informational gathering requires a large video bandwidth and high signal-to-noise ratios, and that advantageous use of an FM system requires as large a deviation as possible—were traded off to allow a maximum video bandwidth of about 200 kc with a deviation ratio near unity. This was the largest informational channel bandwidth yet made available for space applications; however, it is considerably smaller than standard commercial-television channel allocations. The implications were two-fold: that the television camera would need to be designed using the slow-scan techniques pioneered in earlier space missions by Radio Corporation of America (RCA) and that a reliable transmitter with considerably higher power output than previously used would be required to span the 240,000-mile cislunar distance.

Utilization of this 200-kc bandwidth for camera video was then dependent on the realization of a telecommunications system operating with existing DSIF elements that would provide video signal-to-noise ratios in excess of 30 db even at threshold. Parameters available for early consideration, shown in Table 1, indicated that a transmitter power of 15 db above one watt would be required for single-channel operation, and that if simultaneous transmissions over both channels were desired, an additional 3 db of power would be required to overcome losses in the RF combining network. It became clear that the probability of mission success would be best served by simultaneous operation of two transmitting channels. The transmitting channels operate in the following manner. Inputs to the FM modulator contain video frequencies from dc to 200 kc and the telemetry channel in the band of 220 to 230 kc. The modulator consists of baseband amplifiers, a crystal-stabilized voltage-controlled oscillator (VCO), and a buffer amplifier. The VCO is deviated 1/48 of the transmitted signal and operates at about 20 Mc. Both the deviation and center frequency are increased by a factor of 48 through the two varactor doublers and a

Table 1. Summary of communications parameters

Losses	
JPL circuit losses	1.7 db
Spacecraft antenna	−18.1 db
Antenna pointing	0.3 db
Path loss	204.5 db
DSIF antenna	−45.7 db
Receiving circuit	0.4 db
Total	143.3 db
System noise temperature	128.9°K
Noise bandwidth	~800 kc
Receiver noise power	−148.5 db w
Transmitter power	17.8 db
RF combiner and cable losses	3.5 db
Received carrier-to-noise ratio	19.5 db

varactor tripler in the X12 stage and a single-stage varactor quadrupler in the X4 stage. The output is 960 Mc at 150 mw. The IPA cavity uses an RCA-type 7870 tetrode power amplifier to increase the power level to about 6 w. The final boost to an output power of 60 w is provided by a Resdel cavity utilizing a Machlett-type ML-7855 triode operating class "C." The power amplifiers and dummy load are pressurized at 15 psi and the 4-port hybrid ring is of a solid-state design to prevent multipactor and RF arcing at this power level.

With the question of the design of transmitters capable of propagating 900 kc of RF bandwidth at the lunar distance firmly answered, the camera design utilizing the full 200-kc bandwidth also moved ahead.

A ruggedized 1-in.-diameter RCA-ASOS[1] vidicon is the key element in the *Ranger* television camera design. It provides the sensitivity required to capture a latent image during the brief shuttered exposure as the camera platform hurtles toward the Moon at speeds approaching 2700 m/sec. This vidicon effectively stores the latent image while it is converted to an electrical analog signal by operating the camera in a slow-scan mode and provides a fine enough scanning aperture to achieve a significant modulation at spatial frequencies of 35 cycles/mm. These factors weighed heavily in selecting this vidicon as the camera sensor. Reliable operation with minimum weight and power also imposed significant constraints on the camera design. A scanning system was developed which utilizes the vidicon's limiting response of 35 cycles/mm over an active photoconductor area of 11.4 by 11.4 mm. The informational content of the generated video signals can be contained in the allocated 200-kc bandwidth by permitting the entire photoconductive area to be scanned with 1132 scanning lines in 2.56 sec.

It became clear as a probable terminal sequence, shown in Fig. 7, was examined that a closing speed of about 2600 m/sec would be achieved. At that speed the final full picture possible would be taken at an altitude of 6500 m. Optical systems under consideration such as the

[1]Antimony sulfide-oxygen sulfide, a vidicon target material.

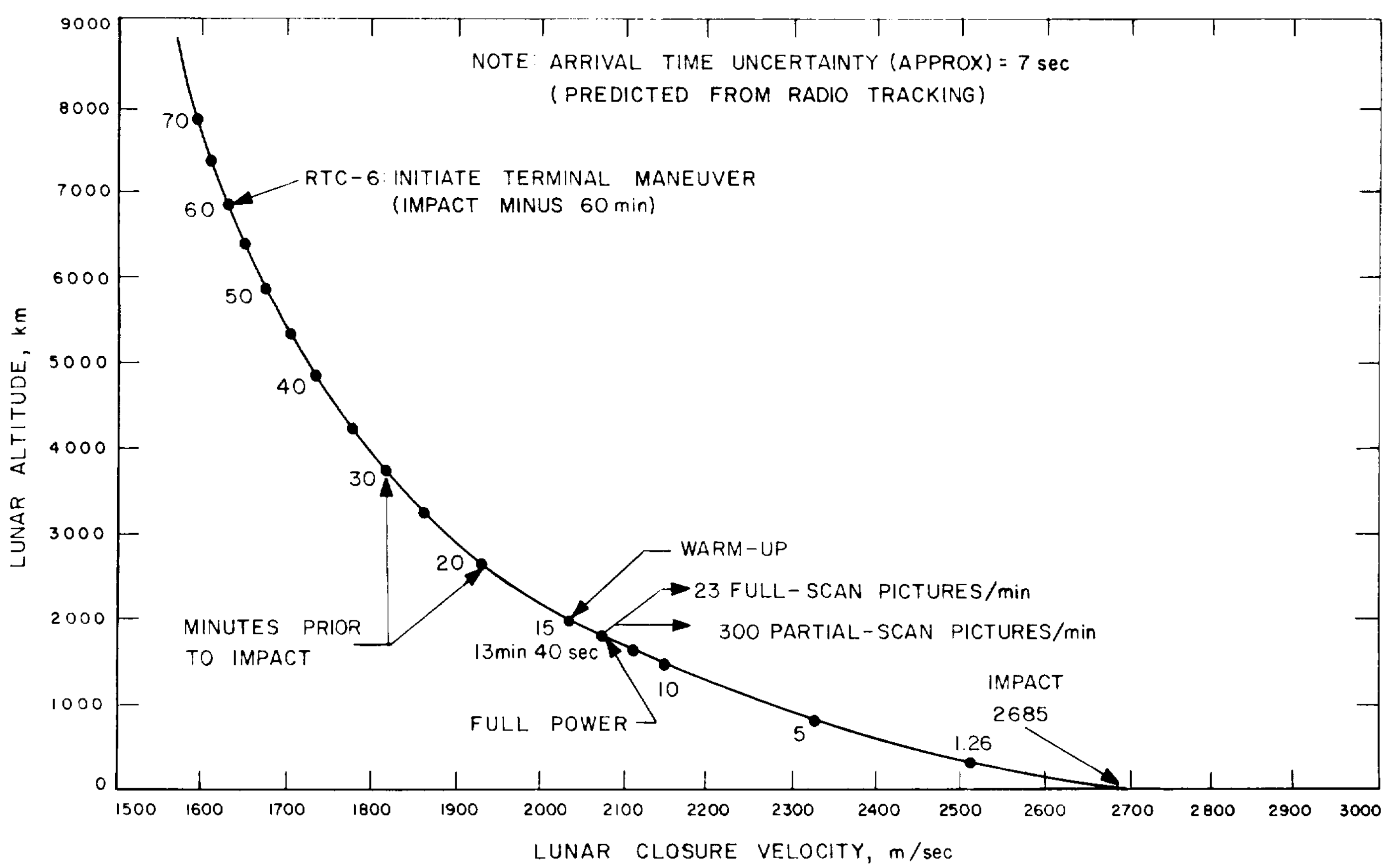

Fig. 7. Lunar closure velocity

Bausch and Lomb 76-mm F/2 Super Baltar at the 35-c/mm system resolution would result in lunar resolution of about 2.5 m/c, an order of magnitude larger than the system expectations. It would be necessary to get closer to the Moon to improve on the final lunar detail if this optical system was to be used. As shown in Fig. 8, the desired detail would be achieved if the final picture could be taken a fraction of a second before impact. With the 200-kc bandwidth limitation it would be necessary to reduce the informational content in this last picture by a ratio of almost 16 to 1. A partial-scan camera was conceived which used all of the equipment of the 2.5-sec-scan full-scan camera, but arranged to utilize this informational and scanning density in a 2.8-mm-square area on the photoconductor. Continued refinement of the cameras lead to the final designs as outlined in Table 2.

At the 2600-m/sec approach velocity, image smear would definitely be a constraining item on photographing detail less than a meter per optical pair. A focal-plane shutter capable of a million operations had been developed for the TIROS program. This shutter, modified to provide a 2-msec exposure, was used in the *Ranger* camera. With this image-immobilization technique it would be possible to reduce translational smear and edge blur to less than the acceptable 0.25 to 0.3 optical line pair for the last or next-to-last picture taken for reasonable trajectories (Fig. 9).

It became evident that the sensitivity of the RCA-ASOS vidicon would be required to capture the latent lunar image with an exposure of 2 msec. A review of lunar

Table 2. Camera parameters

	Full-scan		Partial-scan	
	F_A	F_B	P_3, P_4	P_1, P_2
Lens	25-mm F/0.95	76-mm F/2	25-mm F/0.95	76-mm F/2
Shutter	5 msec		2 msec	
Line rate	450 cps		1500 cps	
Frame time	2.56 sec		0.2 sec	
No. of active scan lines	1132		290	
Photoconductor area	11.4 mm × 11.4 mm		2.8 mm × 2.8 mm	
Vidicon	RCA-ASOS vidicon		RCA-ASOS vidicon	
Weight: Camera	7.0 lb		6.5 lb	
Electronics	6.5 lb		6.5 lb	
Power	13 w		12.0 w	

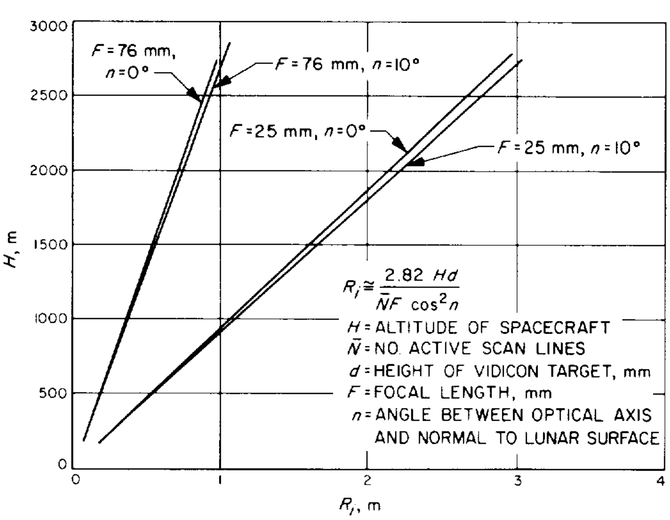

Fig. 8. Intrinsic resolution vs lunar altitude

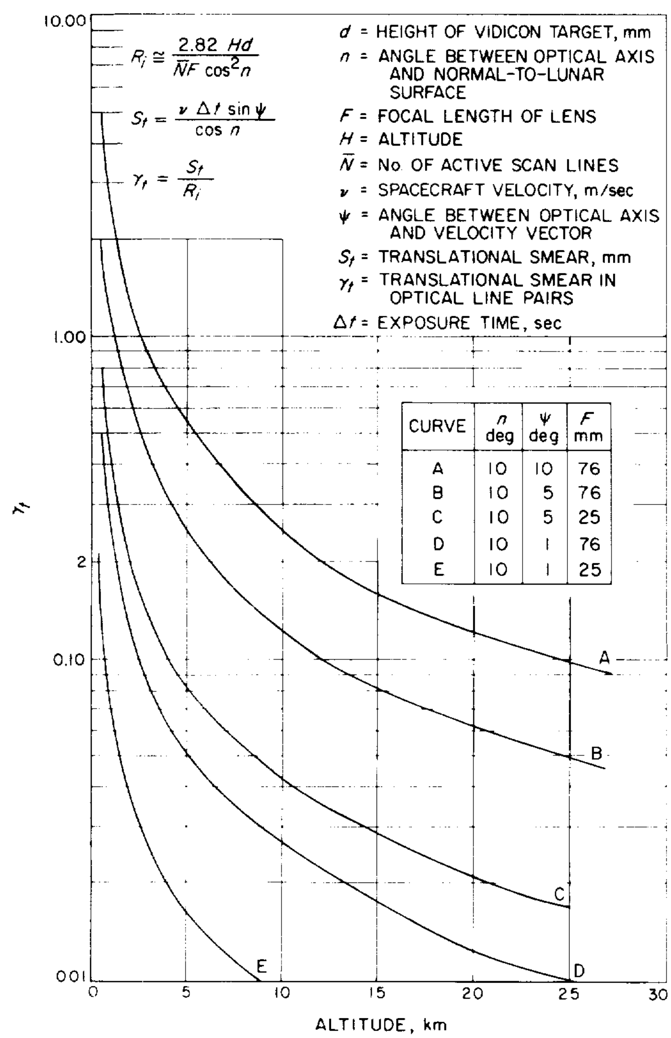

Fig. 9. Translational smear vs altitude

regions of interest indicated that average brightness may be on the order of 200 to 400 ft-L for maria regions about 20 deg from the terminator. This amount of lunar luminance, the exposure required to immobilize the image, the lens aperture ratio, and the integrated illumination of the vidicon's photoconductor are related in the following equation:

$$E \text{ (ft-c-sec)} = \frac{B}{4} \frac{T\Delta t}{(F/\text{No.})^2}$$

where

B = lunar brightness

T = lens transmission

Δt = exposure time

For the 76-mm F/2 lens and a 2-msec exposure the energy on the photoconductor would be about midway on the vidicon transfer curve.

The camera system design now seemed near at hand as the application of this sensitive vidicon in a slow-scan camera was reviewed. It became apparent that the storage capability of the ASOS vidicon would cause residual images on subsequent readouts and that some provision would have to be included in the camera to reduce these residual images remaining from previous exposures. To accomplish this, a ring of erase lamps was located in the camera yoke so that they could flood the photoconductor with light, thus discharging each element after the normal video had been read out (see Fig. 10). To complete this preparation cycle effectively would require an additional 0.6 sec. This reduction in the duty cycle per camera would require an additional three cameras to provide maximum utilization of the available channels. Four such partial-scan cameras could then be arranged

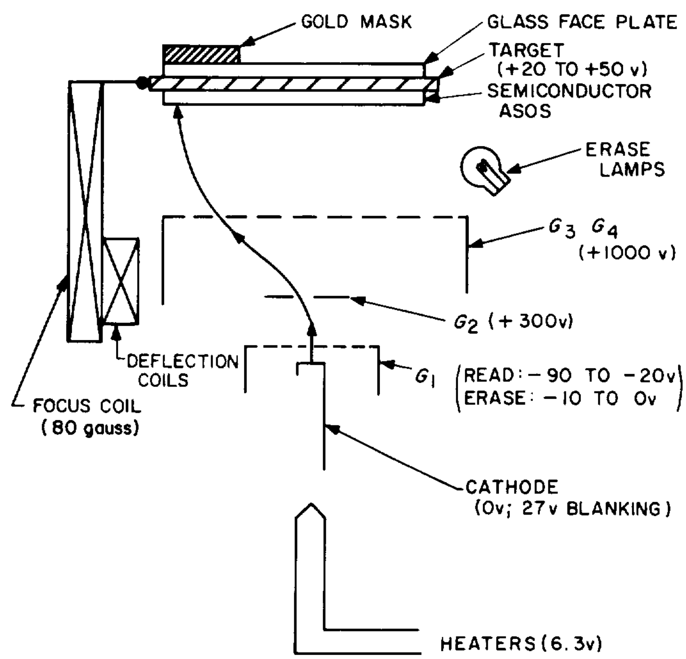

Fig. 10. Vidicon elements

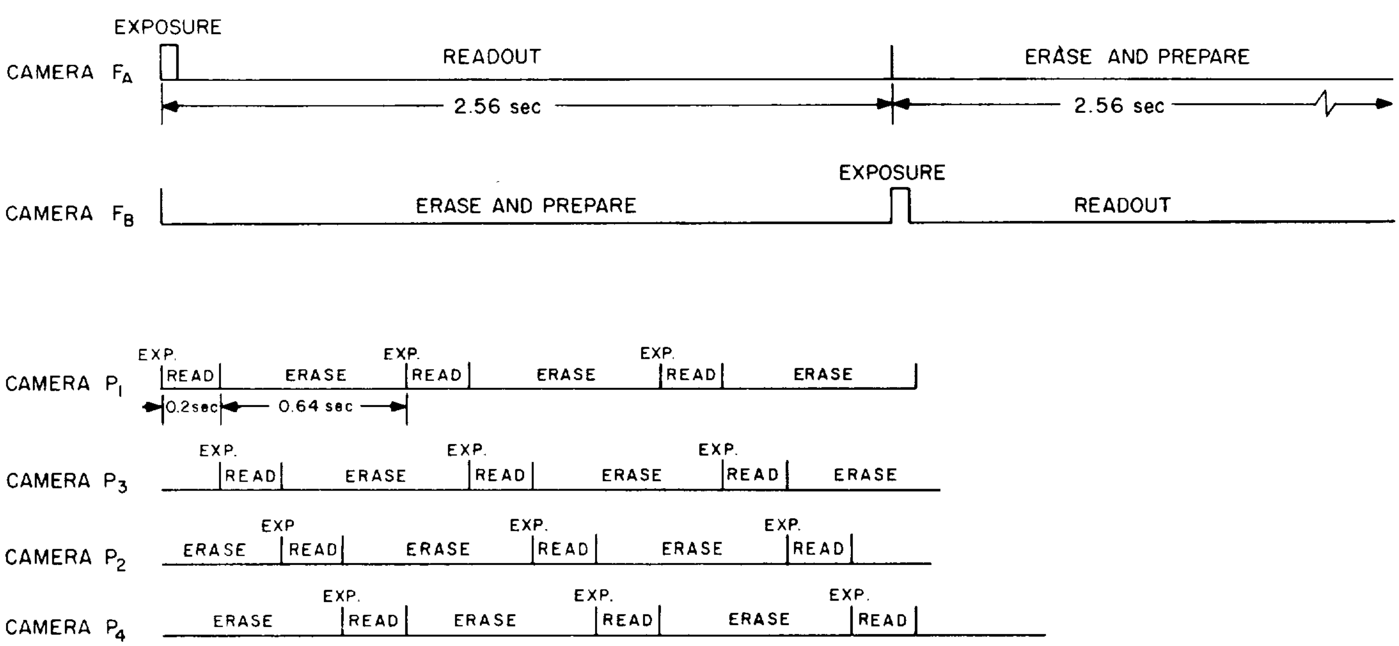

Fig. 11. Camera sequencing program

to provide picture overlap. They would be outfitted with 76-mm F/2 Bausch and Lomb and 25-mm F/0.95 Kodak Augenieux lenses to provide a dynamic range extending from 30 to 2700 ft-L, as shown in Fig. 4. Four cameras sequencing in exposure and readout would also ensure that the last full picture would be captured at a distance less than 1000 m from the lunar surface.

The full-scan cameras also suffer from this vidicon lag problem; however, there would be sufficient time to eliminate these video residuals by sequencing two cameras, one camera being exposed and read out while the other camera is being erased and prepared. A rudimentary sequencing program is shown in Fig. 11.

In this manner a camera system was evolved that would satisfy the mission requirements of high-definition lunar images and that would optimally use the channel allocations and satisfy weight and power constraints. Each television camera would be packaged in two parts: the sensing equipment containing the vidicon, the lens, the deflection and focusing yoke, and shutter in the camera head; and the scanning generators and analog-signal-processing equipment in the camera electronics. The type of circuits and equipment required are illustrated in Fig. 12, the camera block diagram. These camera operational circuits are primarily analog in nature. The programming of the operational sequence for each camera and for the complement of six is more appropriate for digital-processing circuitry; hence, a digitally derived control programmer and camera sequencer was provided for the above operations. The design called for the program to start with two completely independent 18-kc crystal-controlled clocks and power supplies and would, by binary division, generate a sufficient number of gates to provide the control sequences, enumerated in Table 3.

The sequencer not only arranges sequential exposure and camera readout, but arranges to drive open the appropriate gate of the video combiner, permitting only

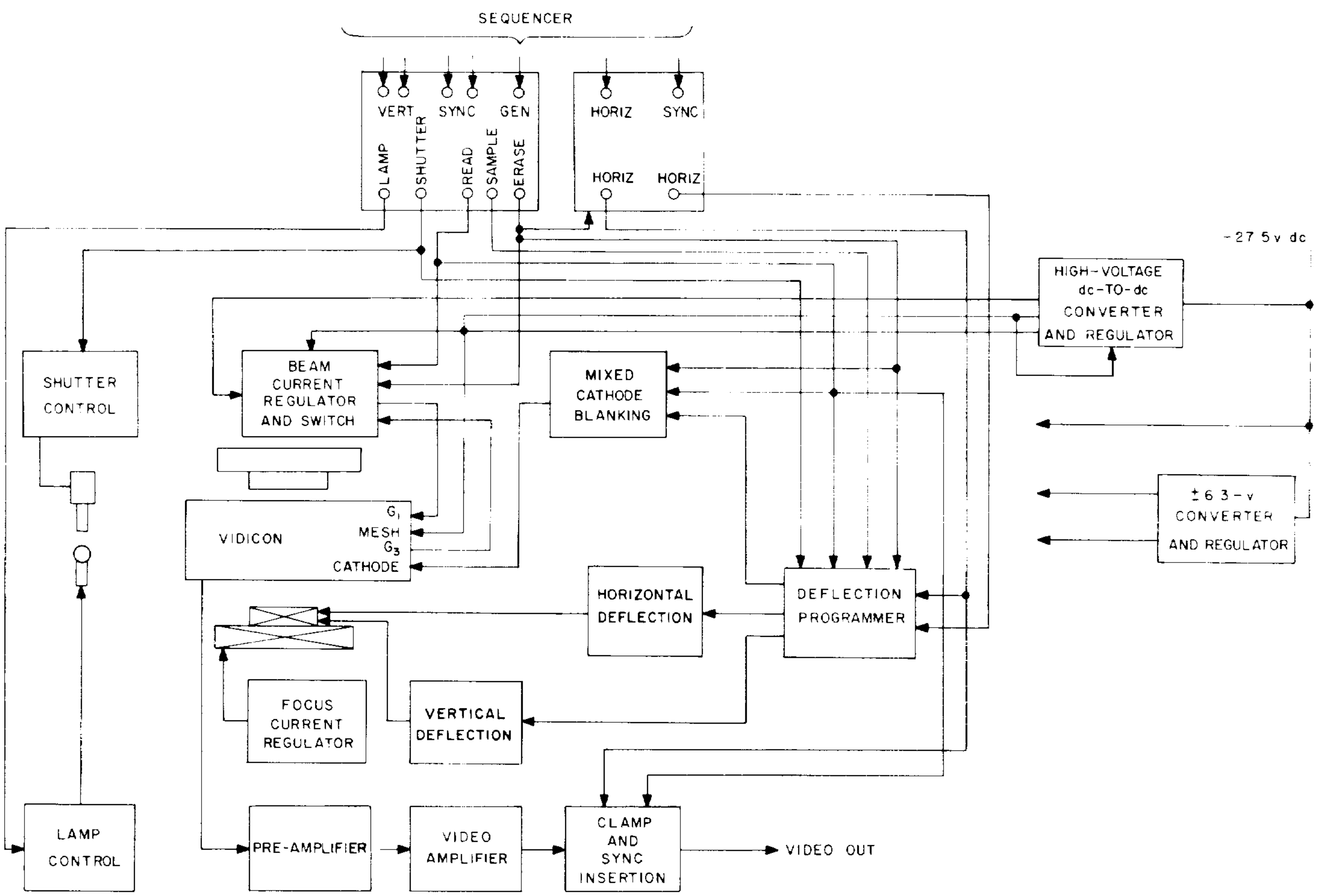

Fig. 12. Camera block diagram

Table 3. Camera control sequences

Partial-scan cameras	Full-scan cameras
Horizontal sync, 1500 cps	Horizontal sync, 450 cps
Vertical read	Vertical read
Shutter drive	Shutter drive
Erase lamp drive	Erase lamp drive
Vertical blanking	Vertical blanking
Black clamp	Black clamp
Video gates F_A, F_B	Video gates P_1, P_2, P_3, P_4

the camera being read out to be connected through to the modulator while the preparation signals from the cameras being erased are inhibited from this modulator connection by appropriate closed gates. The unit that provides this function of impedance matching, serialization of camera video, and additional video processing in the form of "pre-emphasis" is the video combiner. A block diagram shown in Fig. 13 for the P channel illustrates its role in the system. Similar gating is provided for the F channel. Pre-emphasis is added to the video processing to gain a signal-to-noise improvement for video transmission over an FM system. A coarse system block diagram is shown in Fig. 2, which assembles each of the items described as essential to the *Ranger VII* mission for high-detail television pictures of the Moon.

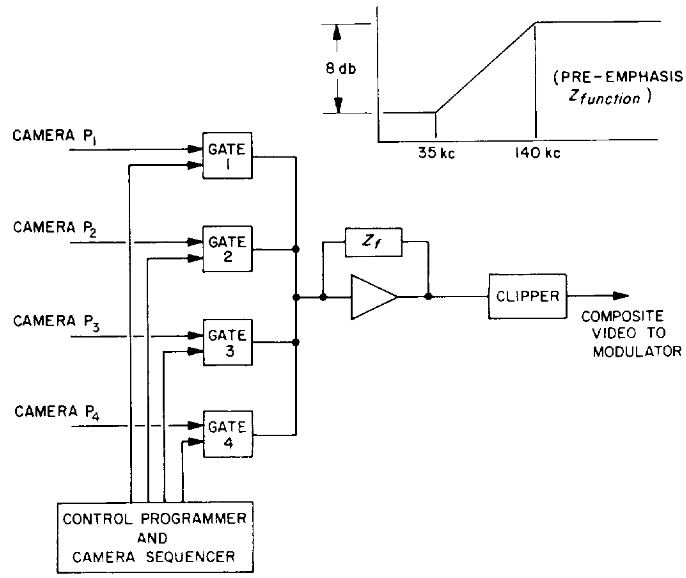

Fig. 13. P-channel video combiner

V. TELEVISION GROUND SYSTEM DESIGN

The signals transmitted from the *Ranger* spacecraft must be reconverted from the electromagnetic domain to the visual domain for use and interpretation by the lunar experimenters. This conversion must be handled with maximum attention to fidelity in visual reproduction of the scene. The design approach to the ground-based receiving and recording equipment (OSE) considered two factors: use of existing, reliable components and redundancy in information storage.

One factor that stands out as having a large effect on the eventual OSE and system design is the selection of the primary data film recorder. It became apparent that the most fruitful film format for a kinescope recording would be provided by a camera featuring rapid film pull-down and sufficient magazine storage to accommodate at least a 15-min mission. A Flight Research 35-mm camera equipped with a data box was chosen. The film would be pulled down in less than 20 msec by a drive pulse derived from the system's vertical sync and be ready for exposure within 46 msec. The camera would be equipped with magazines capable of storing 200 ft of film—more than enough for a 15-min picture-taking mission.

With the basic camera chosen, an optical bench of sufficient mass to reduce vibrational effects on film recording was added to provide the optical configuration for the kinescope- and film-recording camera. The signal flow from image sensing, transmission, signal reception, and reproduction and recording is shown in Fig. 14. The effect of the kinescope recorder is to introduce additional aperture into the overall system. It became important to select elements in this recording chain that would have minimal depressing effects on the final overall system response. The modulation transfer function is shown in Fig. 15 for a kinescope-recording system consisting of a Westinghouse kinescope WX-4877P11, a Cannon 100-mm F/3.5 lens, and Kodak 5374 film. This curve also indicates the effect of these recording elements on the total system response.

the transfer function for each camera and, after the kinescope has been aligned, to specify the development procedure for the film.

The equations which describe the transmission of the film negative in terms of scene brightness are as follows:

$$D = \log \frac{1}{T}$$

$$\gamma_s = \frac{D_2 - D_1}{\log I_2 - \log I_1}$$

$$\gamma_s = \gamma_v \gamma_{CRT} \gamma_F$$

where

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γ_{CRT} = kinescope transfer function

γ_F = film transfer function

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After considerable testing it became clear that the 5374 film developed to a gamma of 1.4 ±0.04 would suit the mission requirements. The setup of the kine-recorder would be:

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VII. MISSION RESULTS

As previously stated, the mission objectives for the *Ranger* TV system were to obtain television pictures of the lunar surface at least an order of magnitude better in resolution than any available Earth-based photography. The best Earth-based photographic records of the Moon currently have a resolution of about one-half mile. Thus

Table 3. Camera control sequences

Partial-scan cameras	Full-scan cameras
Horizontal sync, 1500 cps	Horizontal sync, 450 cps
Vertical read	Vertical read
Shutter drive	Shutter drive
Erase lamp drive	Erase lamp drive
Vertical blanking	Vertical blanking
Black clamp	Black clamp
Video gates F_A, F_B	Video gates P_1, P_2, P_3, P_4

the camera being read out to be connected through to the modulator while the preparation signals from the cameras being erased are inhibited from this modulator connection by appropriate closed gates. The unit that provides this function of impedance matching, serialization of camera video, and additional video processing in the form of "pre-emphasis" is the video combiner. A block diagram shown in Fig. 13 for the P channel illustrates its role in the system. Similar gating is provided for the F channel. Pre-emphasis is added to the video processing to gain a signal-to-noise improvement for video transmission over an FM system. A coarse system block diagram is shown in Fig. 2, which assembles each of the items described as essential to the *Ranger VII* mission for high-detail television pictures of the Moon.

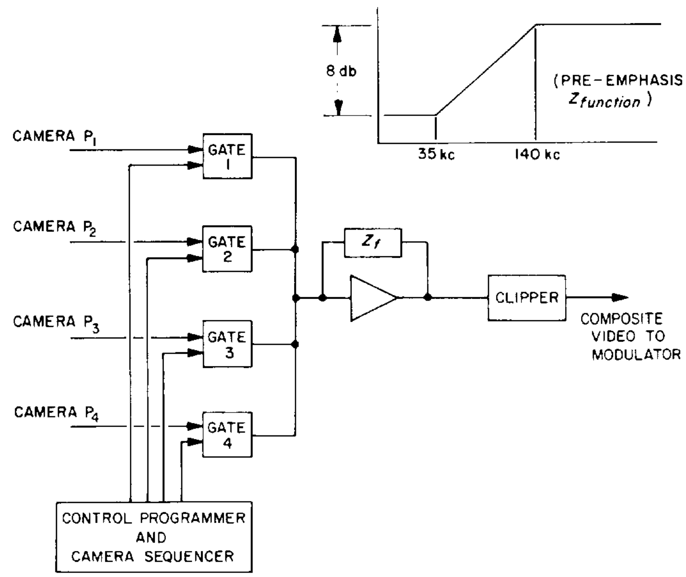

Fig. 13. P-channel video combiner

V. TELEVISION GROUND SYSTEM DESIGN

The signals transmitted from the *Ranger* spacecraft must be reconverted from the electromagnetic domain to the visual domain for use and interpretation by the lunar experimenters. This conversion must be handled with maximum attention to fidelity in visual reproduction of the scene. The design approach to the ground-based receiving and recording equipment (OSE) considered two factors: use of existing, reliable components and redundancy in information storage.

One factor that stands out as having a large effect on the eventual OSE and system design is the selection of the primary data film recorder. It became apparent that the most fruitful film format for a kinescope recording would be provided by a camera featuring rapid film pull-down and sufficient magazine storage to accommodate at least a 15-min mission. A Flight Research 35-mm camera equipped with a data box was chosen. The film would be pulled down in less than 20 msec by a drive pulse derived from the system's vertical sync and be ready for exposure within 46 msec. The camera would be equipped with magazines capable of storing 200 ft of film—more than enough for a 15-min picture-taking mission.

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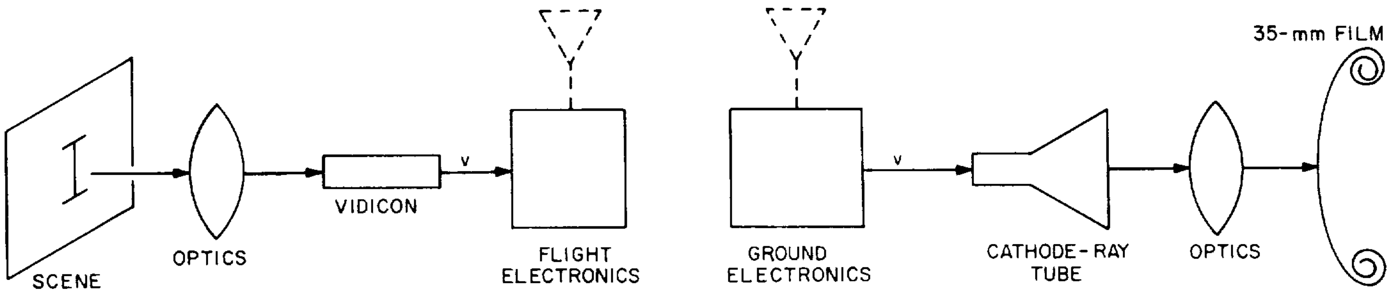

Fig. 14. *Ranger* image-sensing, transmission, reproduction, and recording chain

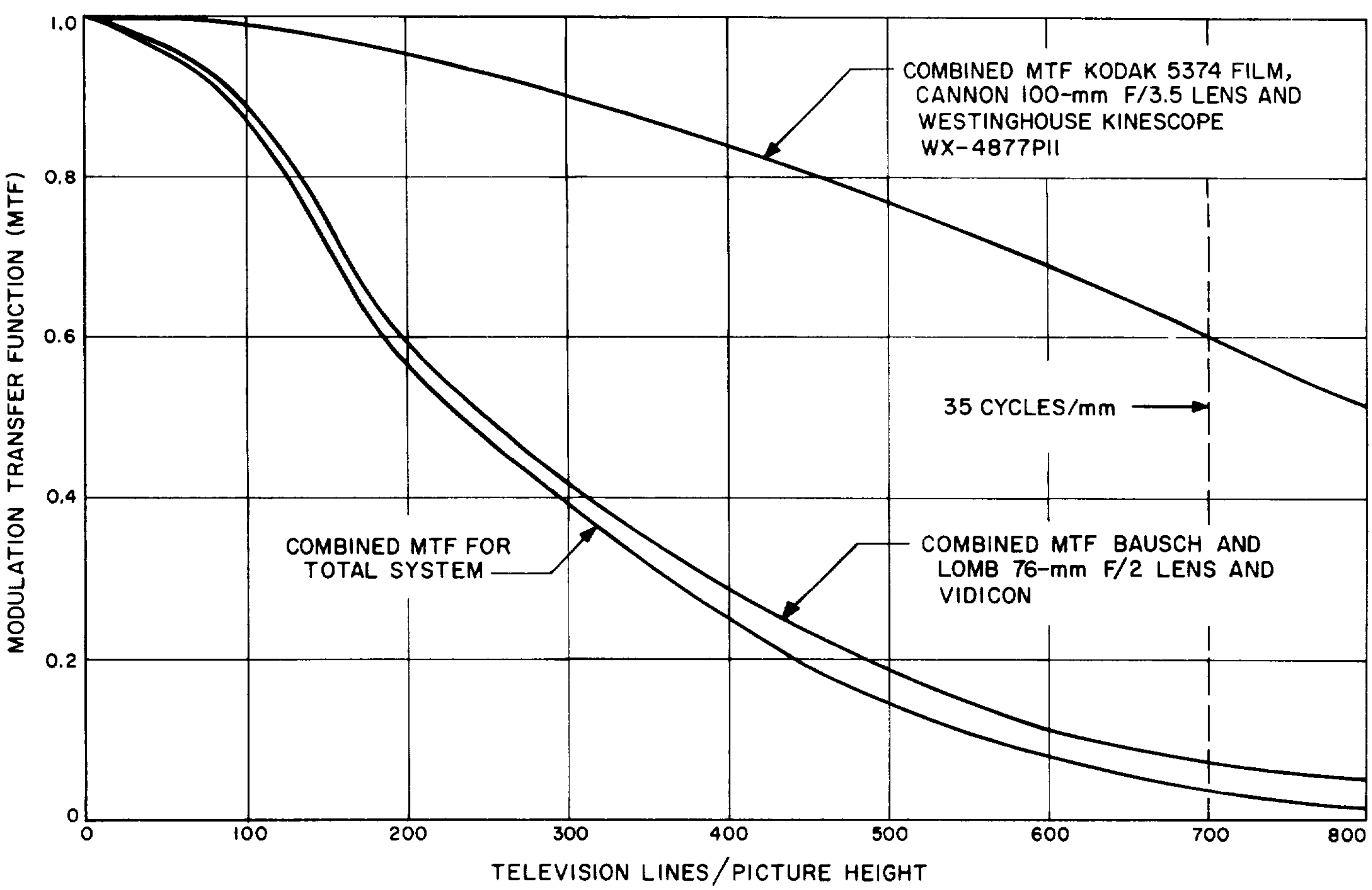

Fig. 15. Modulation transfer function

An important decision in the early design effort of the kinescope-recording system was that it should have provisions for self-checking. To this end a sync and video simulator was designed that would provide signals simulating the partial and full-scan camera video. These signals which included grating patterns, resolution bursts, and grey scales at the vidicon gamma, were essential in the alignment and calibration of this part of the system. Another important decision was the implementation of a "quick-look" capability at the kinescope with a Polaroid camera.

To bridge the gap from the DSIF tracking receiver the television-system receivers were connected in at the 30-Mc intermediate frequency point with a preamplifier capable of handling signals as low as -120 dbm and providing a maximum noise figure of 4 db. The system connections are shown in Fig. 6. The preamplifier directs the signals to a dual-channel receiver, which converts the 30-Mc mixed signal to separate 5-Mc detector amplifiers with a threshold carrier-to-noise ratio of 12 db. The output of each channel's FM discriminator provides a 230-kc bandwidth containing 200-kc video bandwidth and telemetry on a 225-kc subcarrier. Separation of these two is accomplished by a low-pass filter with the video output driving a de-emphasis circuit prior to video distribution, and the telemetry output driving a 225-kc discriminator for separation and eventual display of telemetry. The de-emphasis characteristic is the inverse of the pre-emphasis characteristic shown in Fig. 13.

For test purposes an L-band transmitter and an RF head unit were also included in the OSE design. These units would provide for overall loop tests. The test transmitter could be modulated by simulated video signals properly pre-emphasized. The RF head would convert the direct 960-Mc transmission of the TV system or the test transmitter to a 30-Mc signal. This unit is a crystal-controlled receiver, centered at 960.05 Mc with a gain of 25 db and a 2-Mc bandwidth.

Interim storage of predetected received data is accomplished by a multichannel, magnetic-tape recorder. A 1/2-Mc baseband predetected signal is fed to the magnetic-tape recorder from each of the receiver channels. The tape reels contain sufficient tape capacity at a recording speed of 120 in./sec to record a 15-min mission. The tape output is processed by a tape demodulator, which in turn can be connected to the low-pass filter for video and telemetry distribution.

The operational ground-based receiving and recording equipment was designed to be self-checking and capable of independent operation and alignment. Its operation and alignment must be accomplished without ever being operated with the actual TV system in test at JPL and the Air Force Eastern Test Range (AFETR), Cape Kennedy. Final calibrations are performed with magnetic tapes of the camera video made during prelaunch tests at AFETR.

VI. TELEVISION SYSTEM CALIBRATION

Beyond the equipment and system design there lies a large area of importance in the maximum utilization of the information being processed. This is the area of system operation and includes systems alignment and calibration, which significantly enhances the recorded data. The design concerned itself with maximum information acceptance and final reduction with fidelity to fixed records. Detailed procedures, on the other hand, are enforced to ensure proper system alignment and calibration. These procedures call for records of the linearity of the communication system and the overall system transfer function. Other checks include the measurement of the linearity of the modulator, the center frequencies, rate responses, and signal-to-noise ratios of the TV system transmitting equipment. The receivers and demodulators are also checked for linear response. These alignments are routine in setting up a special-purpose FM receiving system.

The final goal of the alignment and calibration of the video processing and recording equipment is to permit a direct interpretation of the degree of transmission of the 35-mm negatives in terms of scene brightness. To achieve this capability, it is necessary to align the amount of modulation in the transmitters as a function of vidicon face-plate illumination. It is also necessary to calibrate the transfer function for each camera and, after the kinescope has been aligned, to specify the development procedure for the film.

The equations which describe the transmission of the film negative in terms of scene brightness are as follows:

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Even the early frames, which were close to Earth-based resolution, are of scientific value because (1) they show a new aspect of the Moon, and are, therefore, of

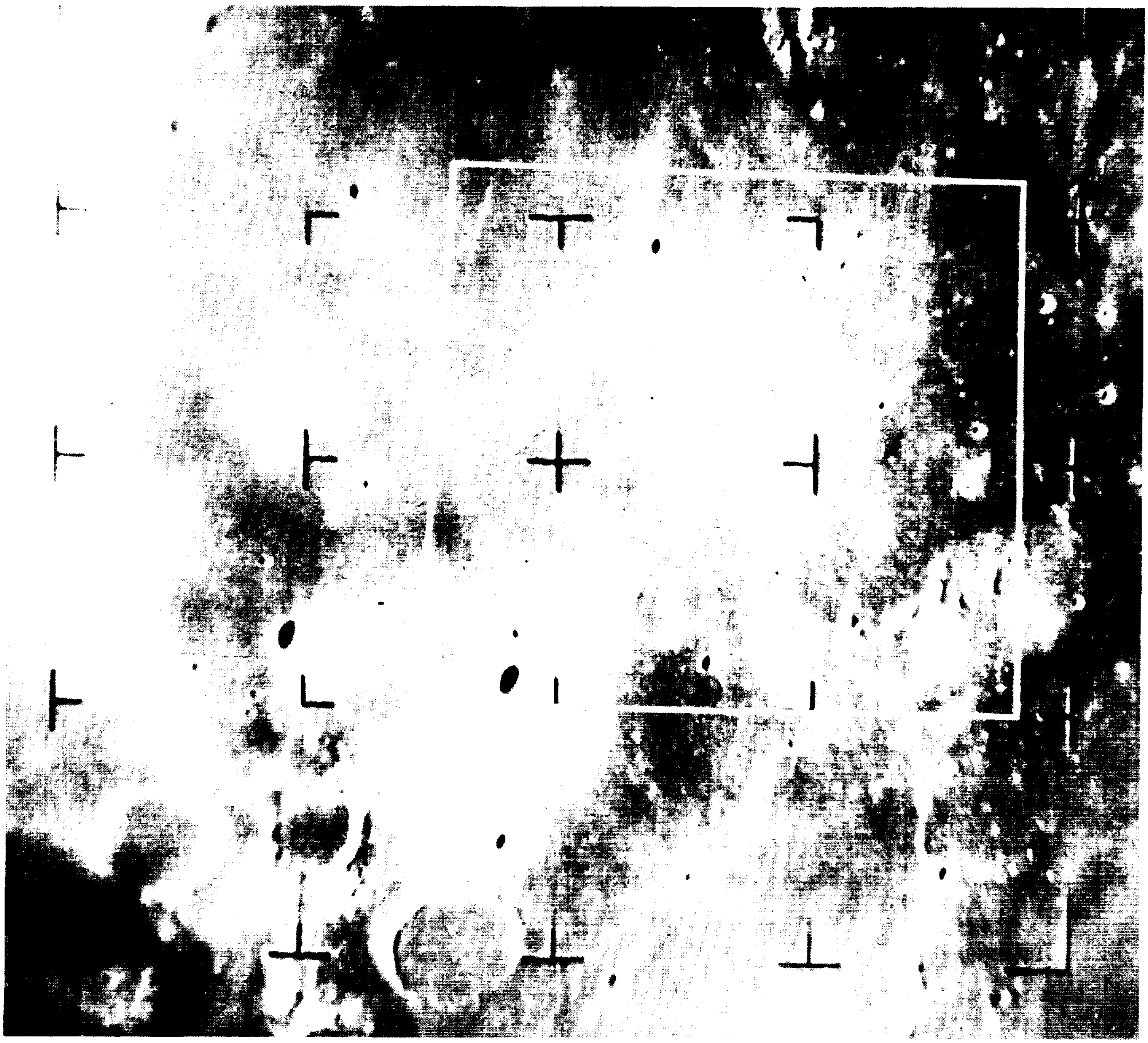

Fig. 16. Lunar photograph taken by the F_A camera with a 25-mm, F/1 lens from an altitude of 480 miles

photogrammetric value; (2) they provide important information of internal positional accuracy and consistency of the records; and (3) they provide photometric controls and other checks on camera and TV performance.

While it may appear from the above numbers that the mission objectives were rather conservative, it should be pointed out that these objectives take into account all the parameters associated with the *Ranger* mission. These include such items as booster performance, tracking accuracy, midcourse maneuver accuracy, spacecraft bus performance, TV system performance, and lunar-encounter conditions. As stated previously, all of these parameters were near optimum, so that it is not surprising that the results of the *Ranger VII* flight were so excellent.

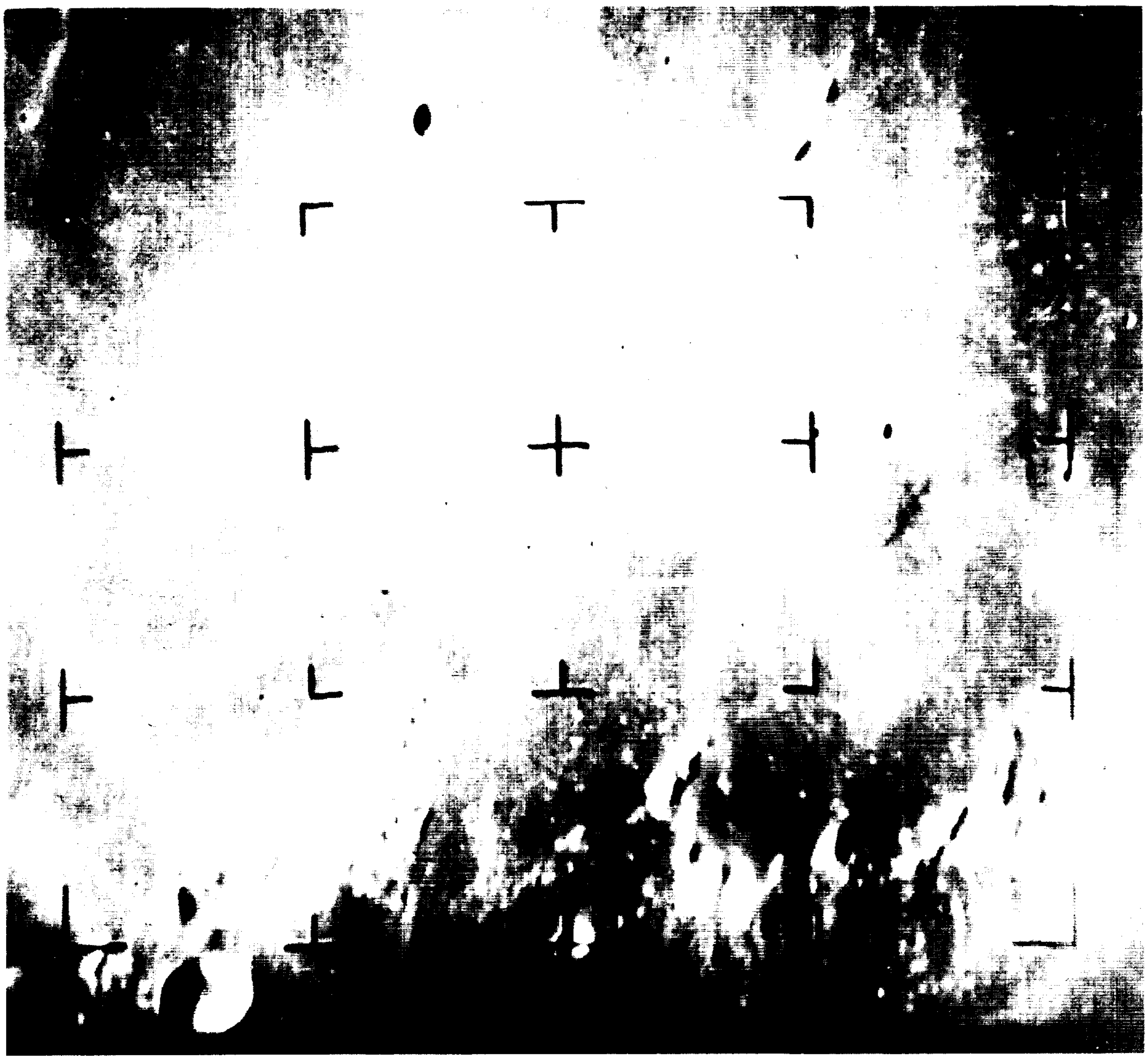

Fig. 17. This picture was taken by the F_A camera with a 25-mm, F/1 lens at an altitude of 235 miles. Smallest craters are about 1,000 ft in diameter

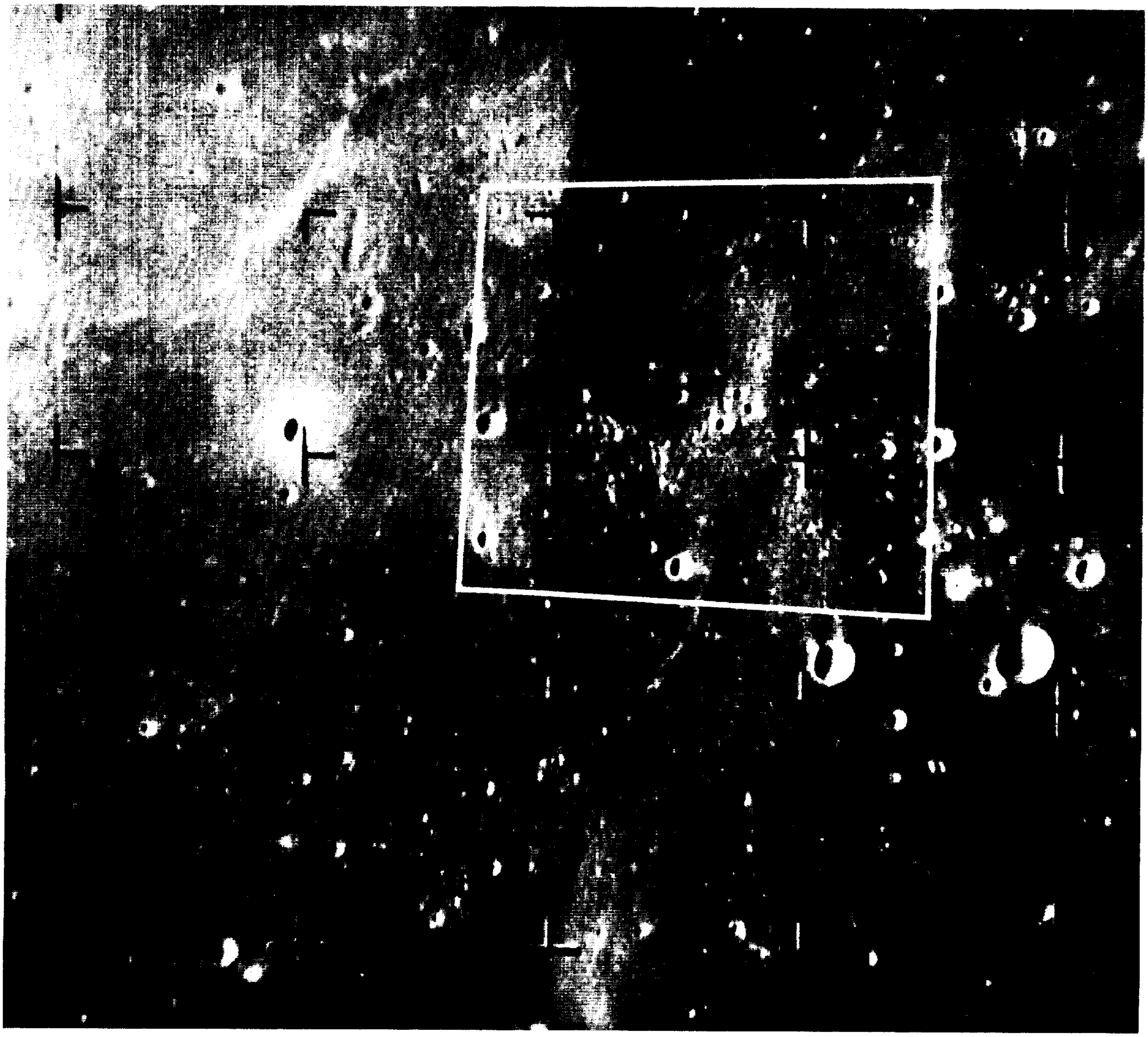

Fig. 18. Photograph taken by the F_A camera with a 25-mm, F/1 lens from an altitude of 85 miles; shows craters as small as 500 ft in diameter

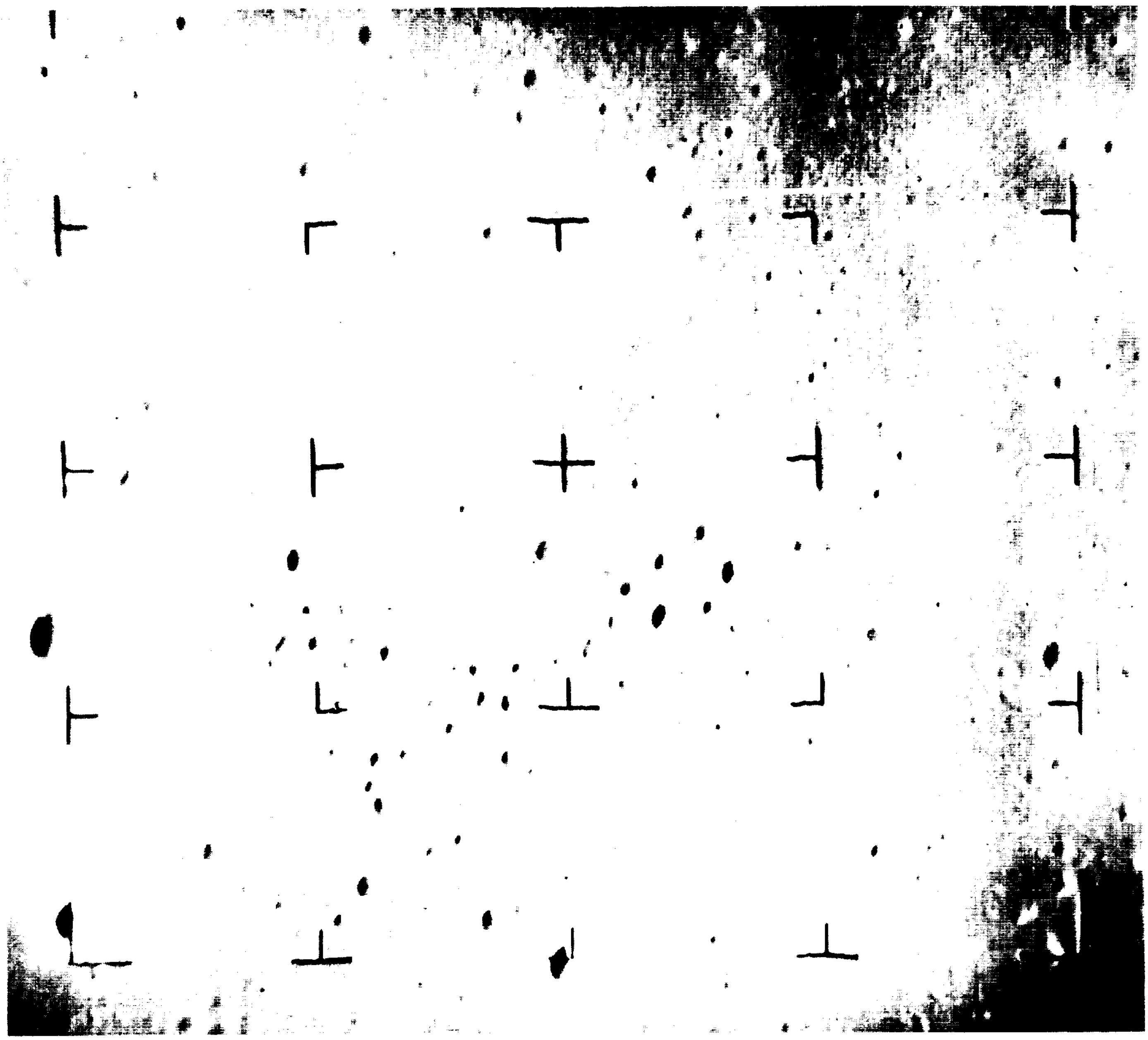

Fig. 19. Photograph taken by the F_A camera with a 25-mm, F/1 lens from an altitude of 34 miles, showing craters as small as 150 ft in diameter

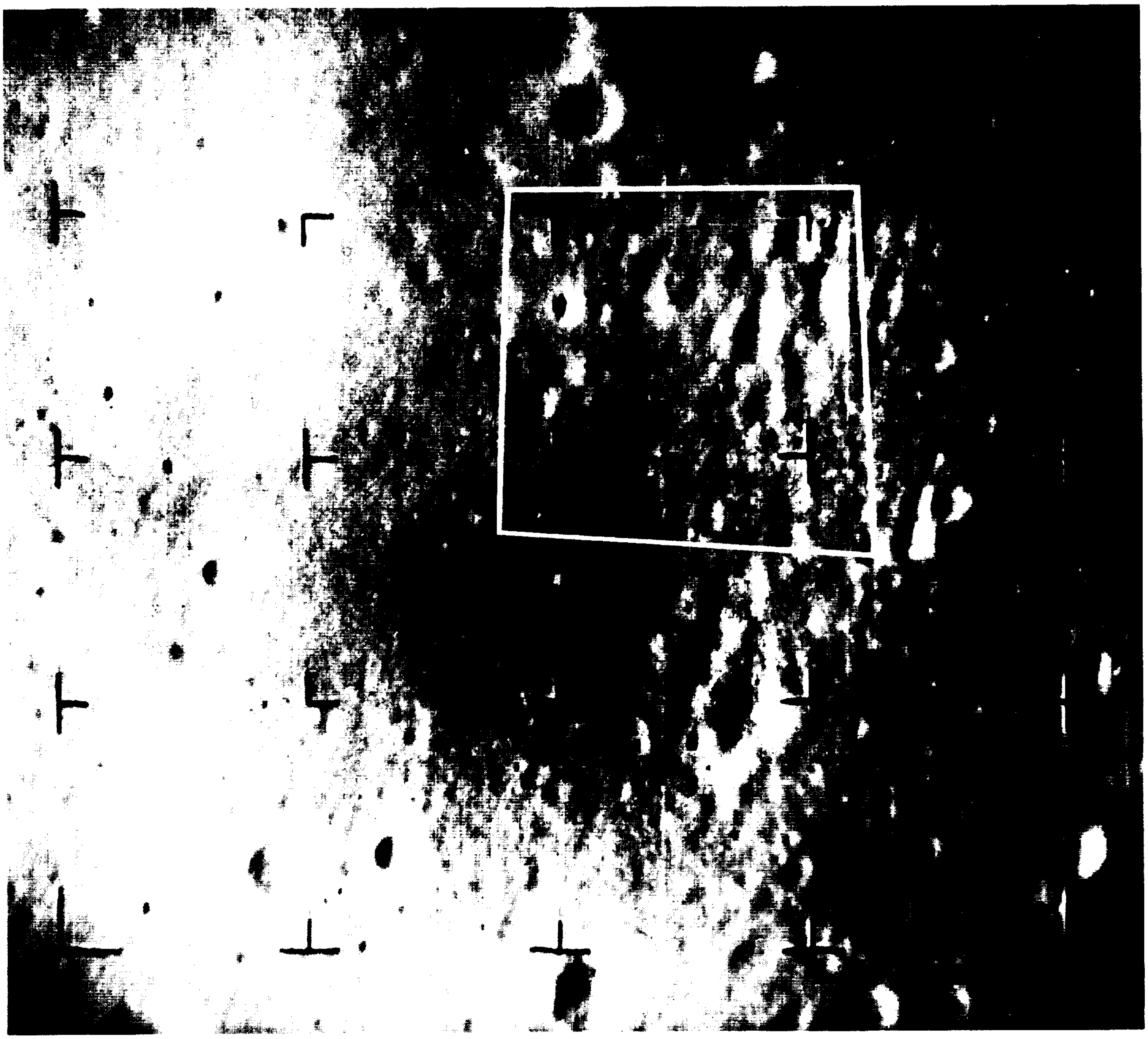

Fig. 20. Picture taken by the F_A camera with a 25-mm, F/1 lens from an altitude of 12 miles, showing craters as small as 45 ft in diameter

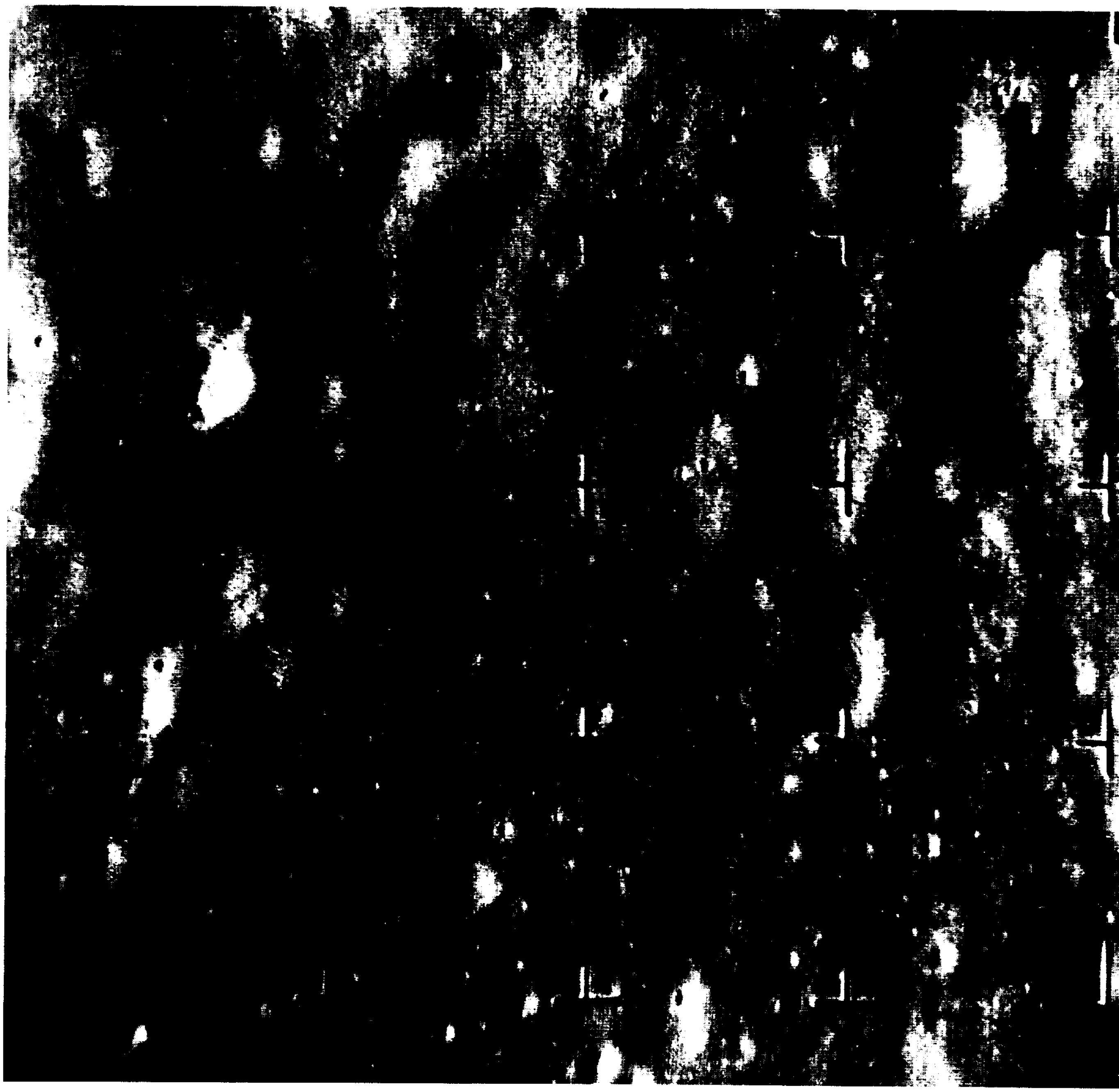

Fig. 21. Photographed just prior to impact. The picture was taken by the F_A camera with a 25-mm, F/1 lens from an altitude of about 3 miles some 2.3 sec before impact; smallest craters approximately 30 ft in diameter and 10 ft deep

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